

# Working Group 1 Summary Muon Acceleration

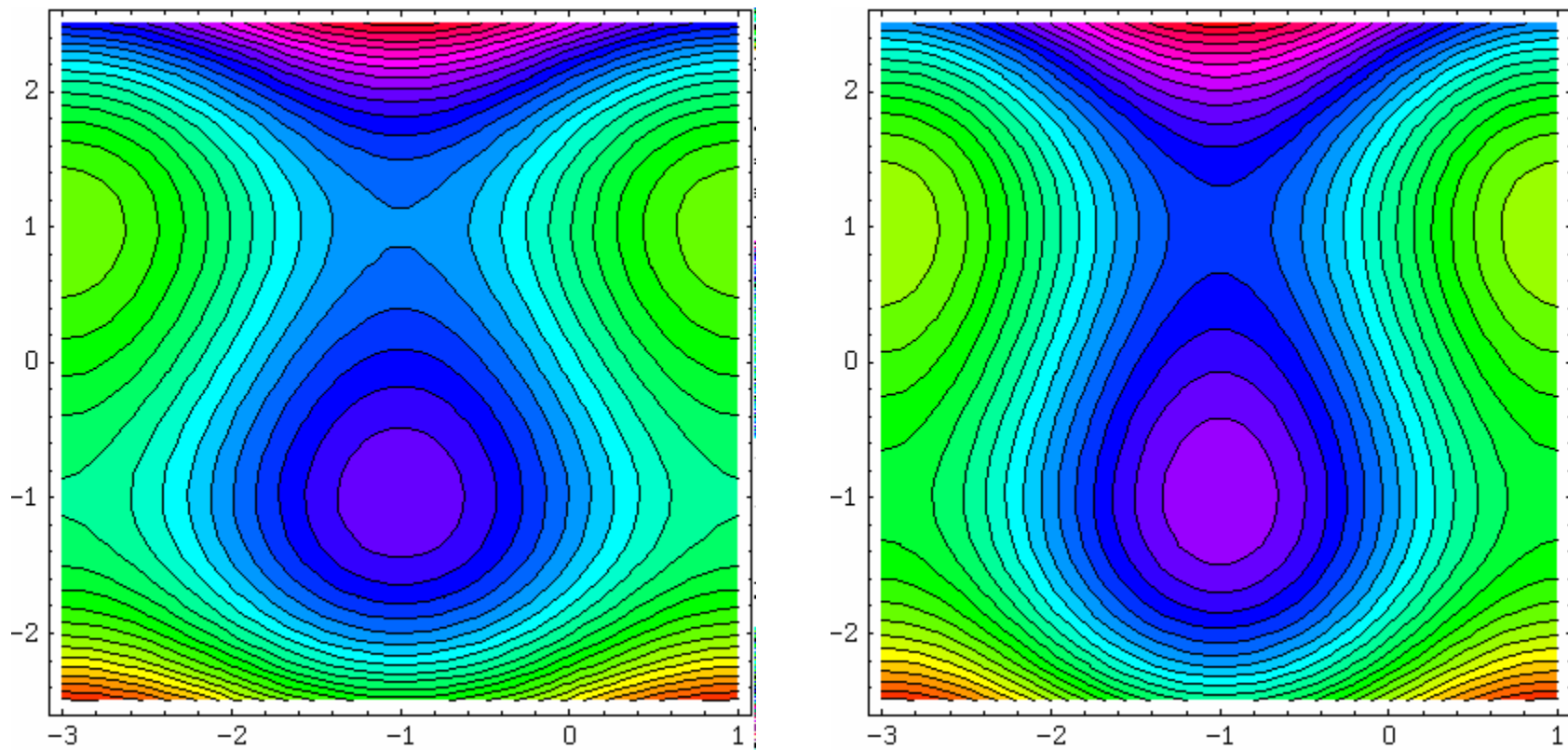
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12 July 2003  
FFAG03, KEK

- Longitudinal dynamics
  - ◆ Non-scaling
  - ◆ Scaling
- Lattice design
  - ◆ Triplet arrangement
  - ◆ Parameter dependencies
  - ◆ Low-energy lattices
- Tracking results in non-scaling FFAGs
- Semi-scaling design

- There were presentations describing the longitudinal dynamics in non-scaling FFAGs with fixed frequency
- One can write the problem in dimensionless variables; main parameter is  $V/(\omega\Delta T\Delta E)$ 
  - ♦  $V$  is installed voltage,  $\Delta T$  is difference between minimum and maximum time-of-flight
  - ♦ More phase space volume transmitted when parameter is larger
  - ♦ Parameter has a minimum value to transmit anything
- Trying to push through too much phase space area results in significant distortions
  - ♦ Higher harmonic seems to help
- Want to keep  $\Delta T$  low to require less voltage
- Lower frequency helps, but not below about 200 MHz
- Low energy: velocity variation gives significant contribution to  $\Delta T$

Width or phase space acceptance of gutter depends on cavity voltage above the critical value of  $\lambda_c=2/3$

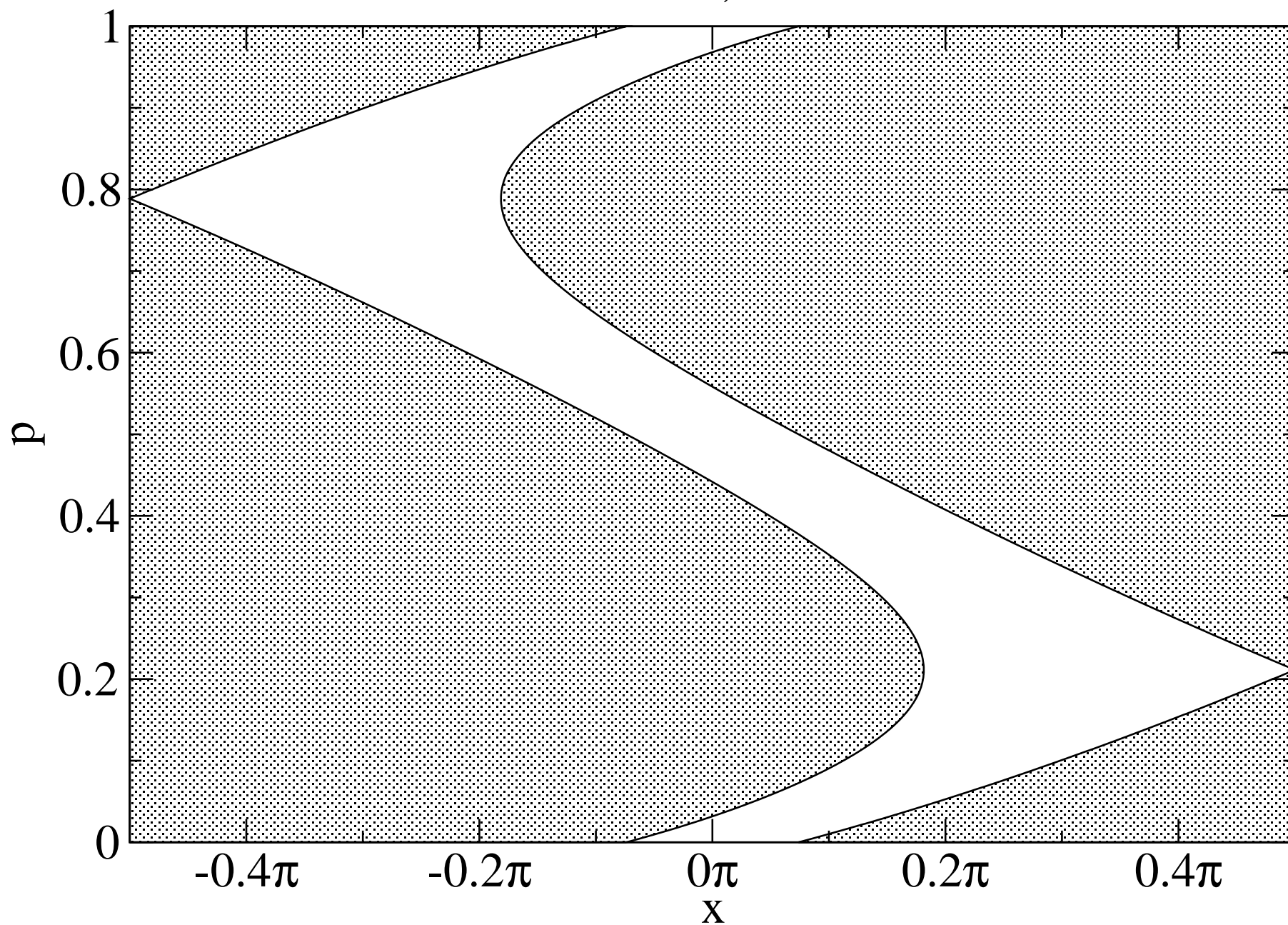
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Quadratic pathlength dependence, or nonscaling FFAG

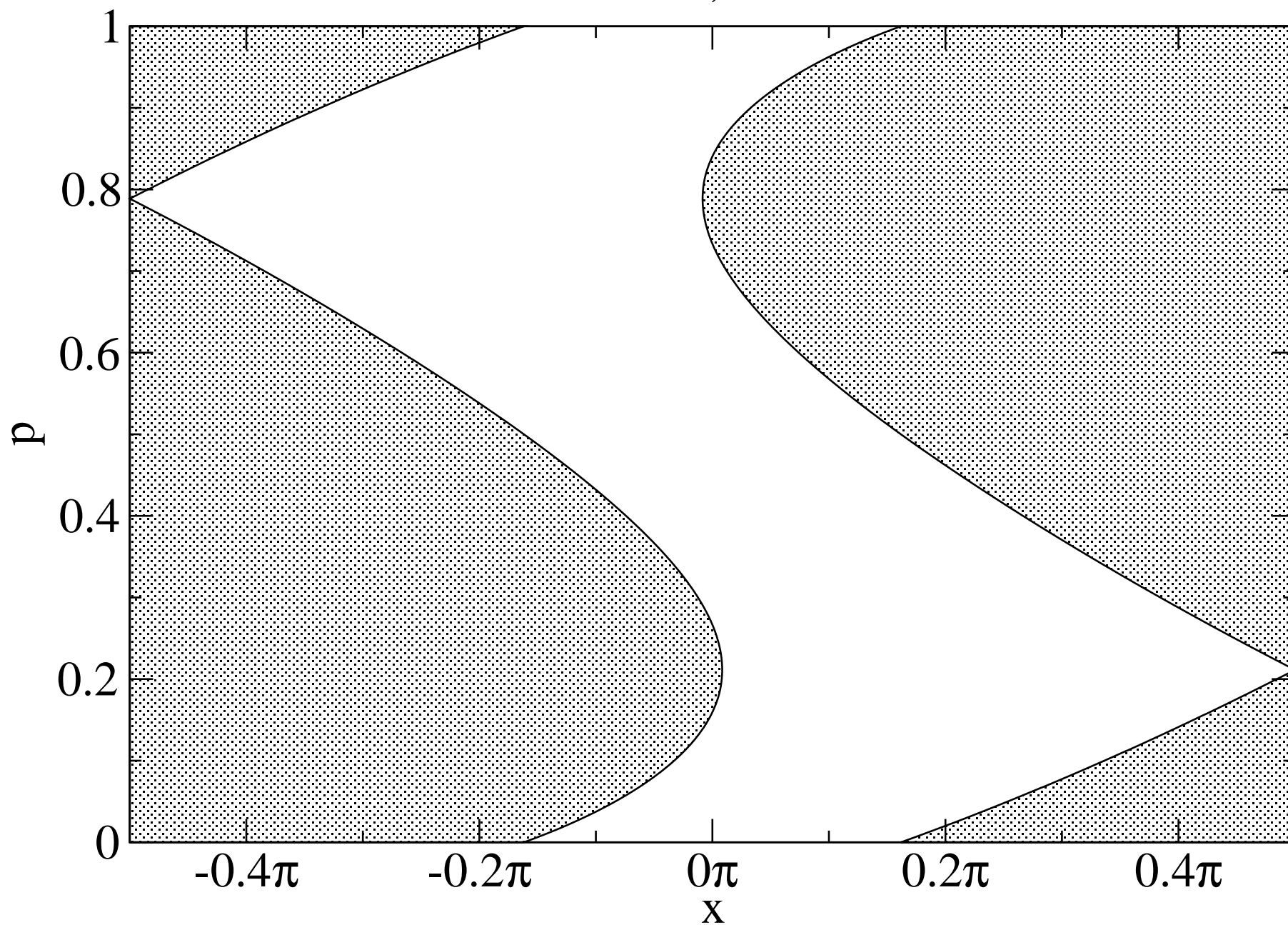
# Longitudinal Phase Space, Non-Scaling FFAG

$w=1/12, z=1/3$



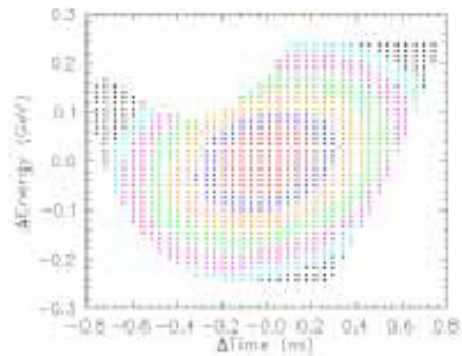
# Longitudinal Phase Space, Non-Scaling FFAG

$w=1/8, z=1/3$

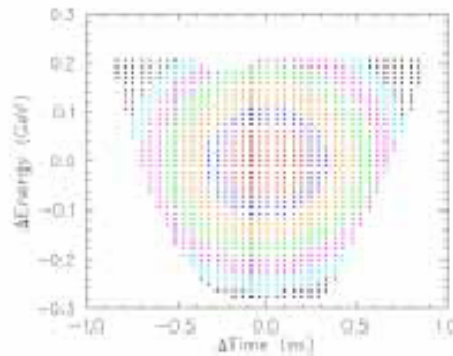


# Asynchronous rf phasing, fixed initial cavity phase

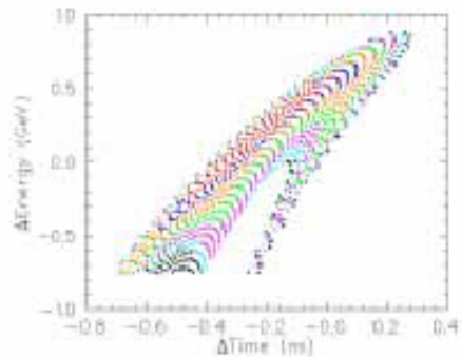
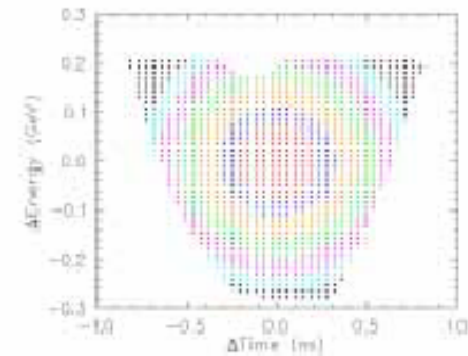
6-turn



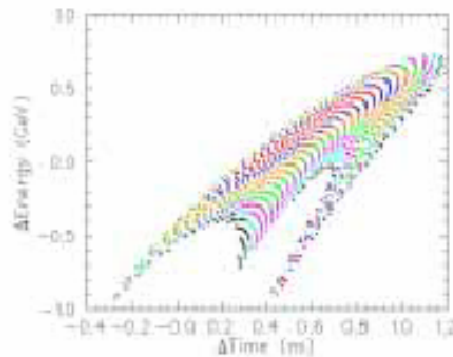
8-turn



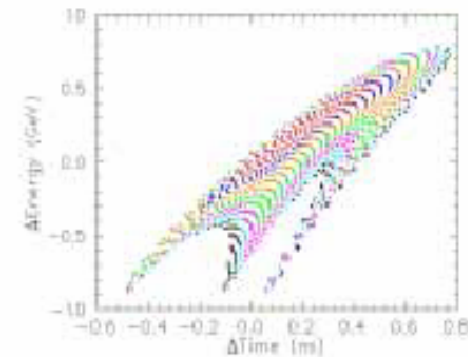
7-turn



fundamental,  $\varepsilon = .49$



+2nd harmonic,  $\varepsilon = .57$

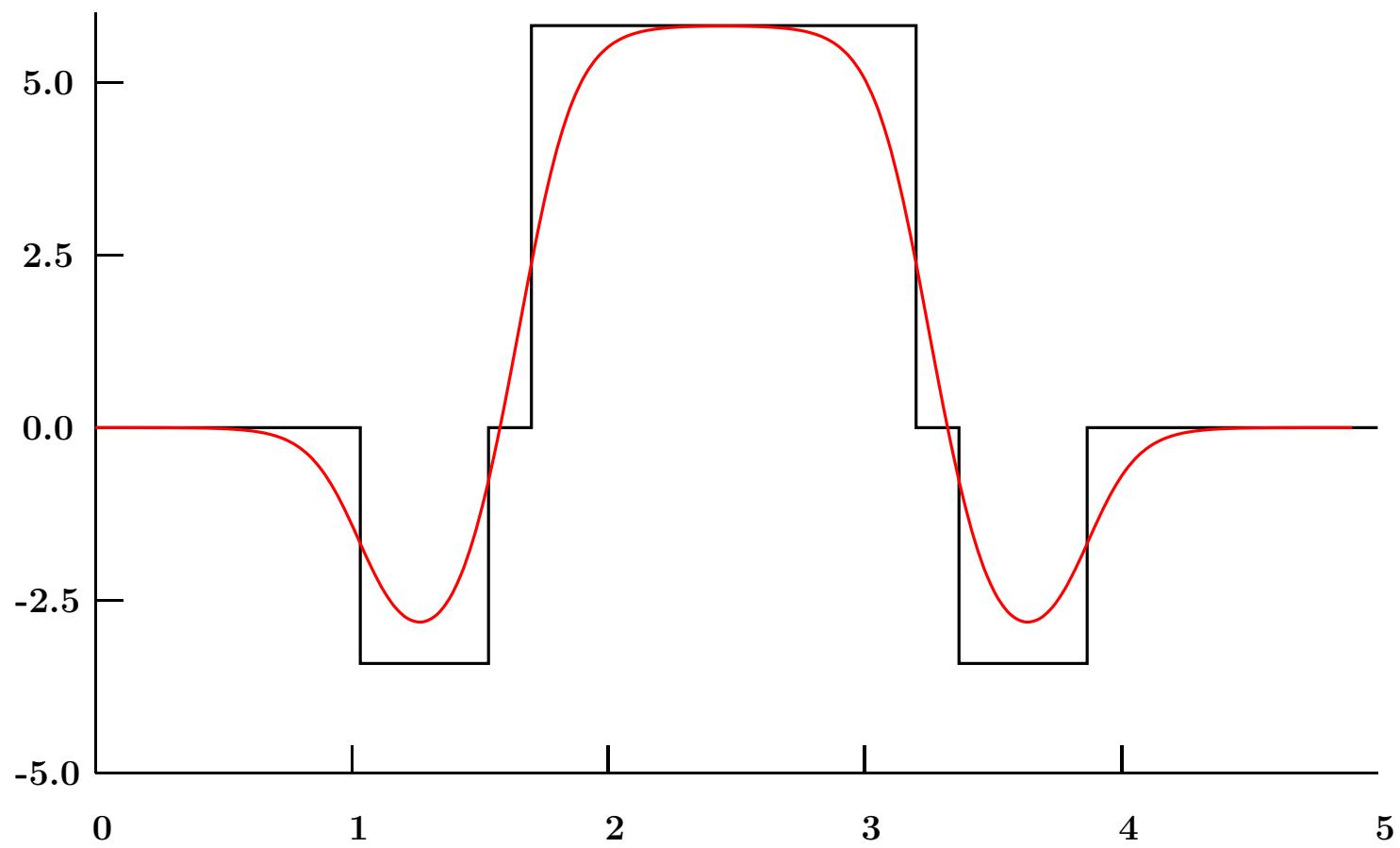


+3rd harmonic,  $\varepsilon = .52$

- In scaling lattice, with fixed frequency, making half a synchrotron oscillation in an RF bucket
- Bucket height must be sufficient to accelerate from minimum energy to maximum
- At low energy, may have transition within your energy range
  - ◆ Dynamics get complicated
  - ◆ Maybe more like non-scaling FFAG
- May be best to go to lower frequency in low-energy stages of scaling FFAGs

- It was demonstrated theoretically that in a triplet lattice, the horizontally defocusing quad should be in the center (FDF)
- In the non-scaling FFAGs, this seems to be true in practice
- Scaling lattices often had a DFD arrangement instead
  - ◆ In some cases this is to keep vertical aperture small
    - ★ Orbit excursion requires large horizontal aperture anyhow
  - ◆ Higher  $k$  gets tune closer to  $\pi$ 
    - ★ FDF gives lower tunes than DFD
    - ★ Can raise  $k$  higher in FDF than DFD: lower  $\alpha_C$ , orbit swing

- Focused almost exclusively on FDF triplet lattices
- Much effort was extended to getting lattices with better  $\Delta T$
- It turned out that the lattices got lower  $\Delta T$  by
  - ◆ Reducing the drift space between quadrupole magnets
    - ★ Minimum amount of space needed for coil return: about 1 magnet diameter
    - ★ Space for diagnostics: but probably can put in drift between cavity and magnets
    - ★ Trim coils, but hopefully can build into quads
    - ★ Field overlap in close coils may increase pole tip fields required
  - ◆ Increasing pole tip fields
    - ★ Must optimize for cost
  - ◆ Increasing RF real-estate gradients (or equivalently reducing the longitudinal phase space transmission)
    - ★ Limited by cavity gradient and cell length

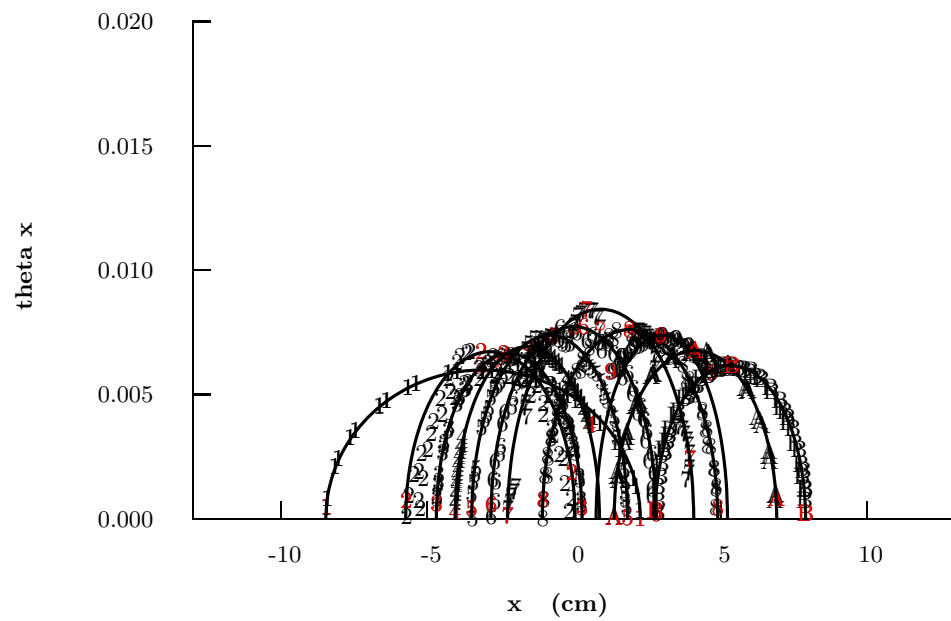
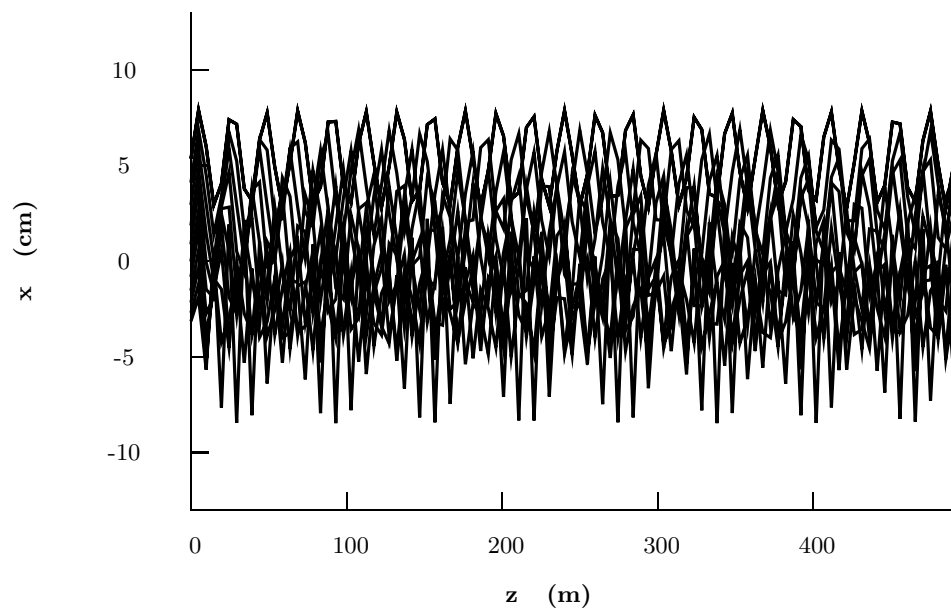
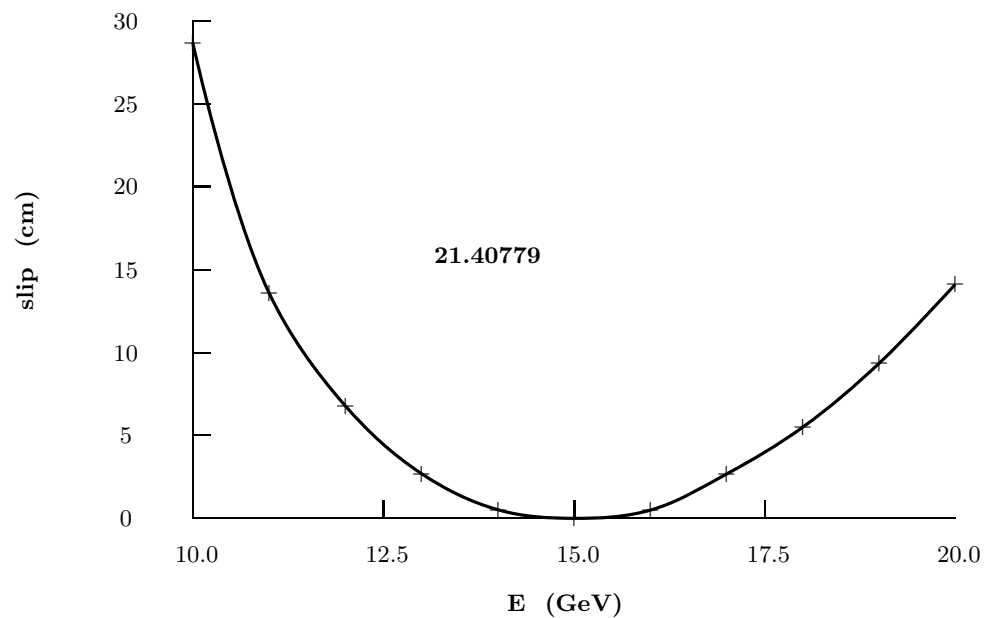
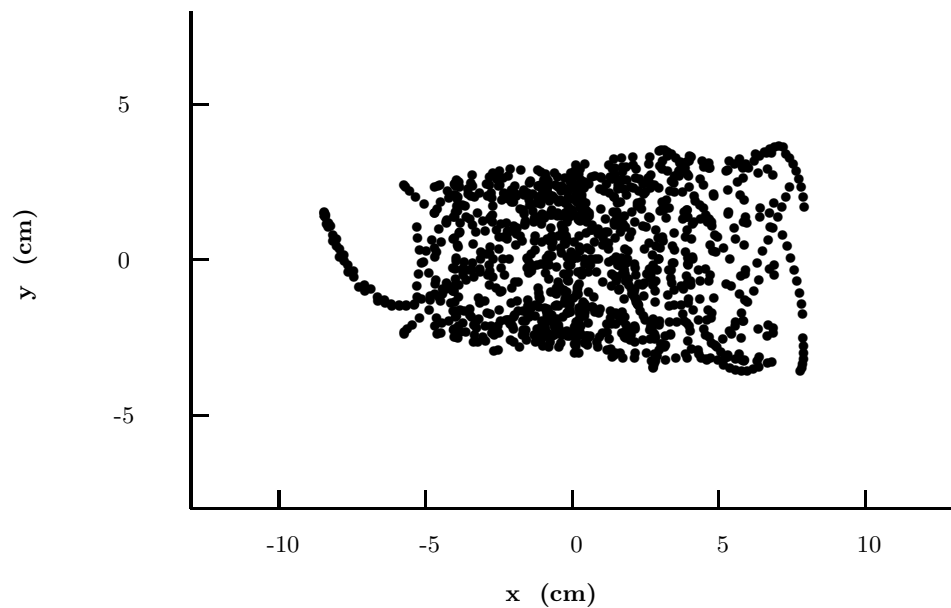


# Lattice Design: Low-Energy Lattices

- Initial lattices that were proposed gave great difficulties starting in the 2.5–5 GeV range
- Problem at least partially coming from large  $\Delta T$  contribution from velocity variation with energy
- A couple lattices were developed which seem to have improved performance over the initial proposal

- Lattices were tracked using two different codes
- There is a significant correlation between transverse amplitude and time-of-flight
  - ◆ May need to correct design for this coupling
- No particle loss found at maximum desired amplitude
  - ◆ Fringe fields didn't seem to have a significant effect
  - ◆ Strong nonlinear coupling effects at high amplitude
    - ★ May need to add extra overhead to aperture (debate on this)
  - ◆ Low level of sextupoles to try to correct  $\Delta T$ :
    - ★ Significant distortion but no loss: OK, but probably can't add more
    - ★ But still didn't help  $\Delta T$

## Dejan first fflag 30 pi mm (q4a)



$p=20 \text{ GeV}/c$   
Phase-space plots are observed at center of QF

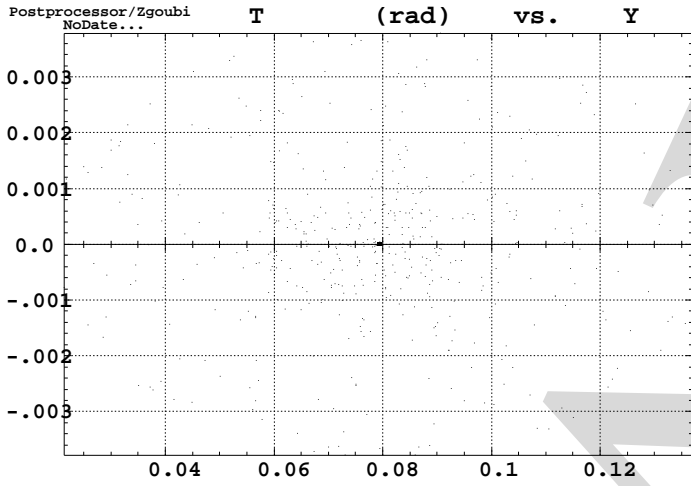


Figure 5: 20GeV, horizontal motion of the particles shown on the right graph.

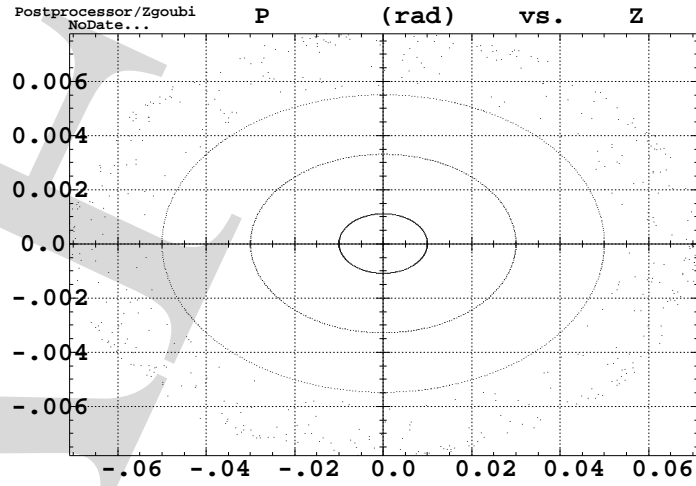


Figure 6: 20GeV, vertical motion of particles launched with  $x, x'$  on closed orbit and various  $z$  values. 500 turns.

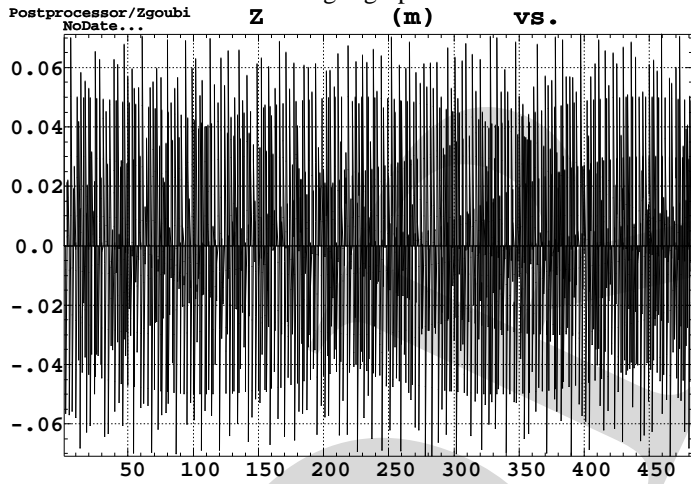


Figure 7: 20GeV, plot of  $Z$  vs. turn number, showing that the motion of particle #7 launched with  $Z_0 = 7 \text{ cm}$  stays confined.

- Semi-scaling lattices
  - ◆ Use scaling-style magnets, but radius not with respect to machine center
  - ◆ Introduce longer straights
- Miscellaneous longitudinal tracking results
- A couple thoughts on a non-scaling lattice designed to Japanese input beam specs
- Ideas on improving a triplet lattice to get better performance
- Things I've forgotten...

- We have made progress in understanding what makes an FFAG perform better
  - ◆ Particular effort has been devoted to triplet lattices, which have not been looked at so much in the past
- We have performed a more detailed analysis of existing FFAG designs
- We obviously need more workshops, since we hardly touched the goals that had been first proposed (due to lack of time, not interest)!
- Thanks to Yoshi Mori, Shinji Machida, M. Yoshimoto, J. Nakano, T. Yokoi, and I'm sure many others, for hosting this conference, taking care of all the arrangements, and helping make this such a successful workshop!